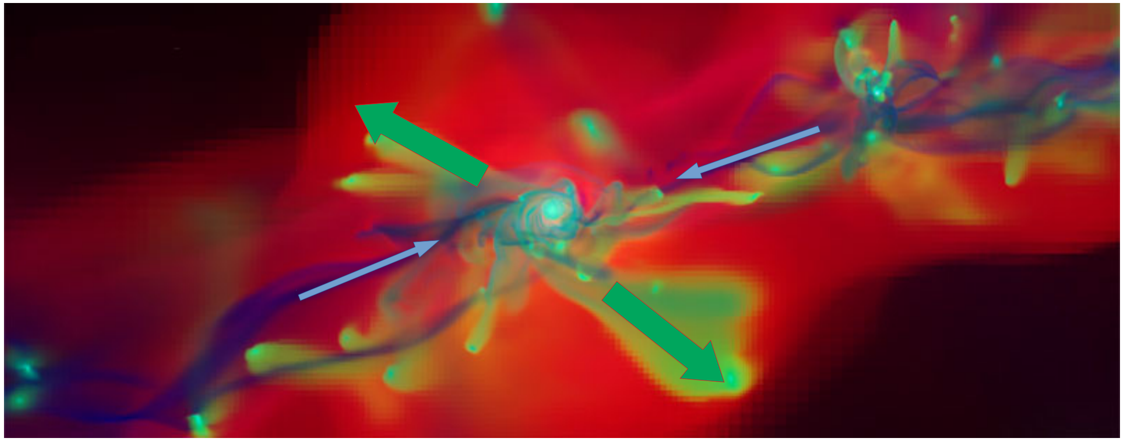
Journée THESEUS France

Absorbers

Pasquier Noterdaeme

Motivations



Outline

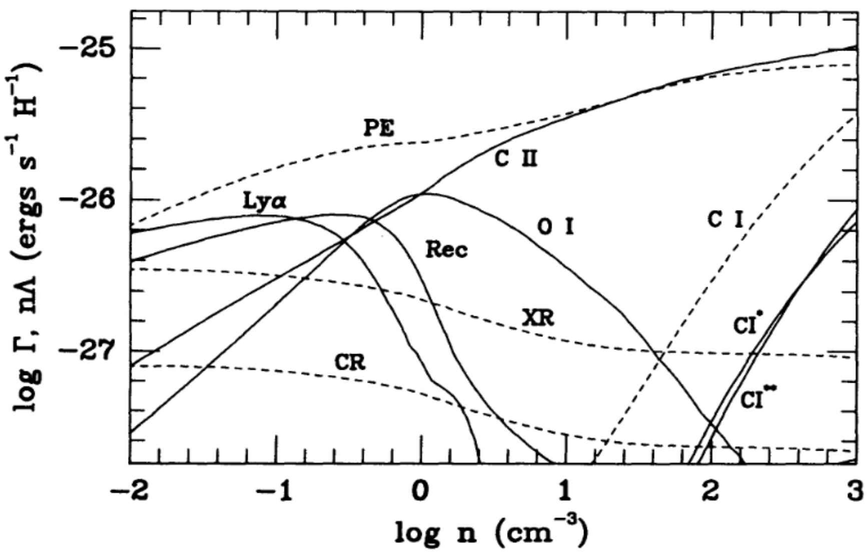
- Absorption in space
- Quasar absorption lines
- GRB absorption lines

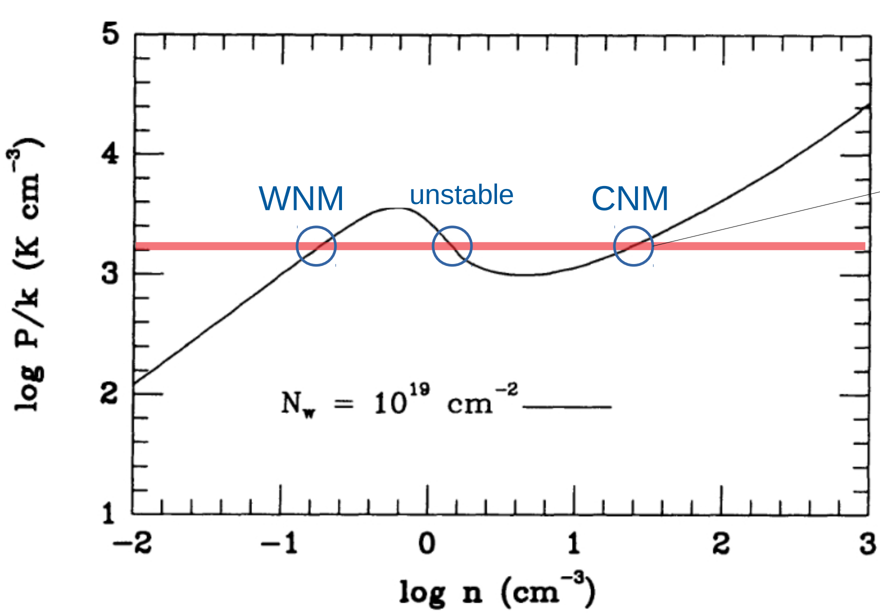
ABSORPTION IN SPACE

- Hartmann (1904): stable CaII absorption lines towards δ-Orionis
  → There is gas between stars
- 1930s-1940s: CN, CH, CH+
- Field et al. (1969): Two-phase model of ISM: CNM+WNM
- Carruthers (1970): H_2
- 1972-1981 : Copernicus (80cm UV telescope + X-ray detector)
- Savage 1977: HI and H_2 census ; gas temperature; critical column density

ABSORPTION IN SPACE

Main paradigm for the neutral ISM





Wolfire et al. (1995,2003)

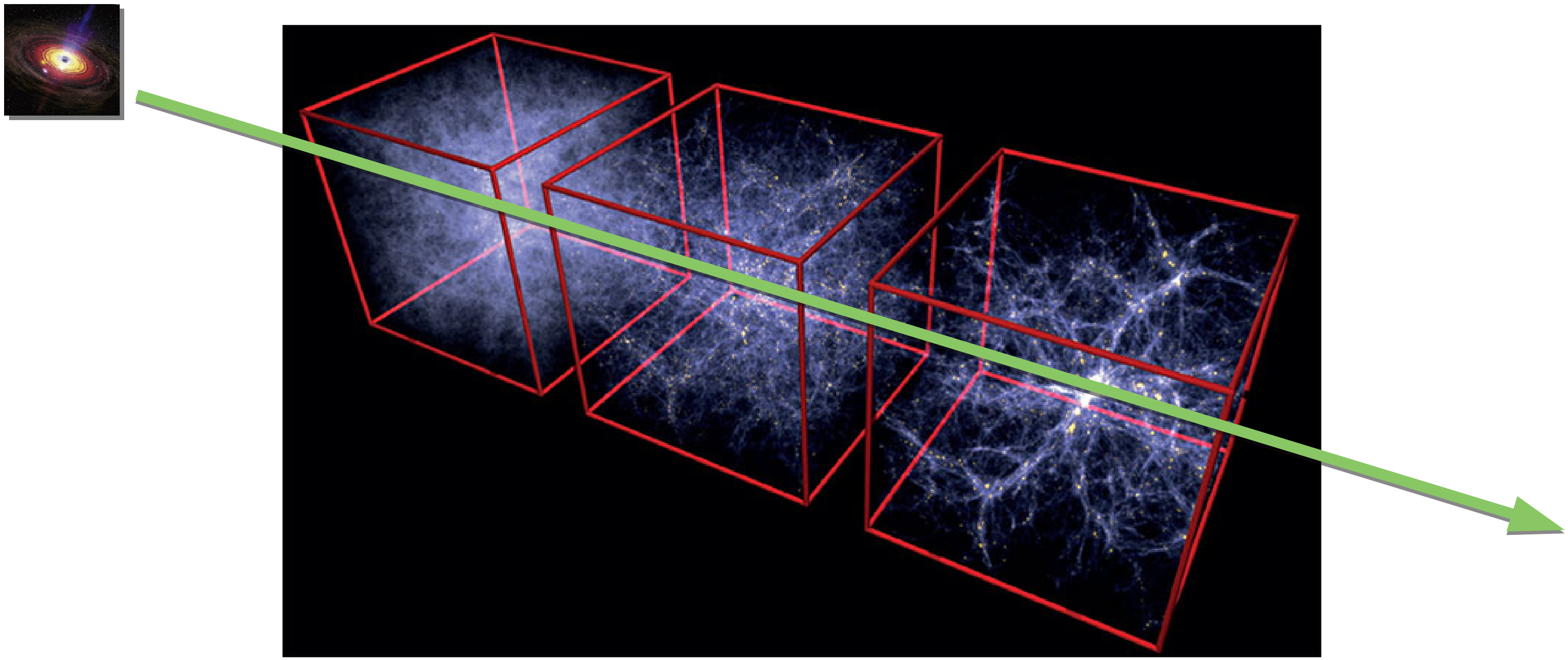
Formation of H_2

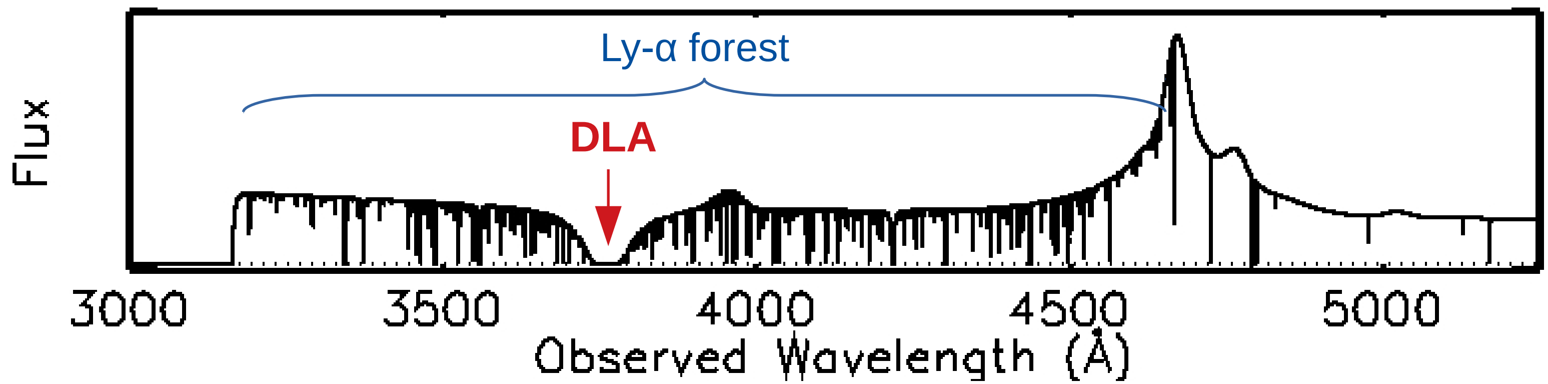
Hydrostatic mid-plane pressure
Blitz & Rosolowsky (2006)

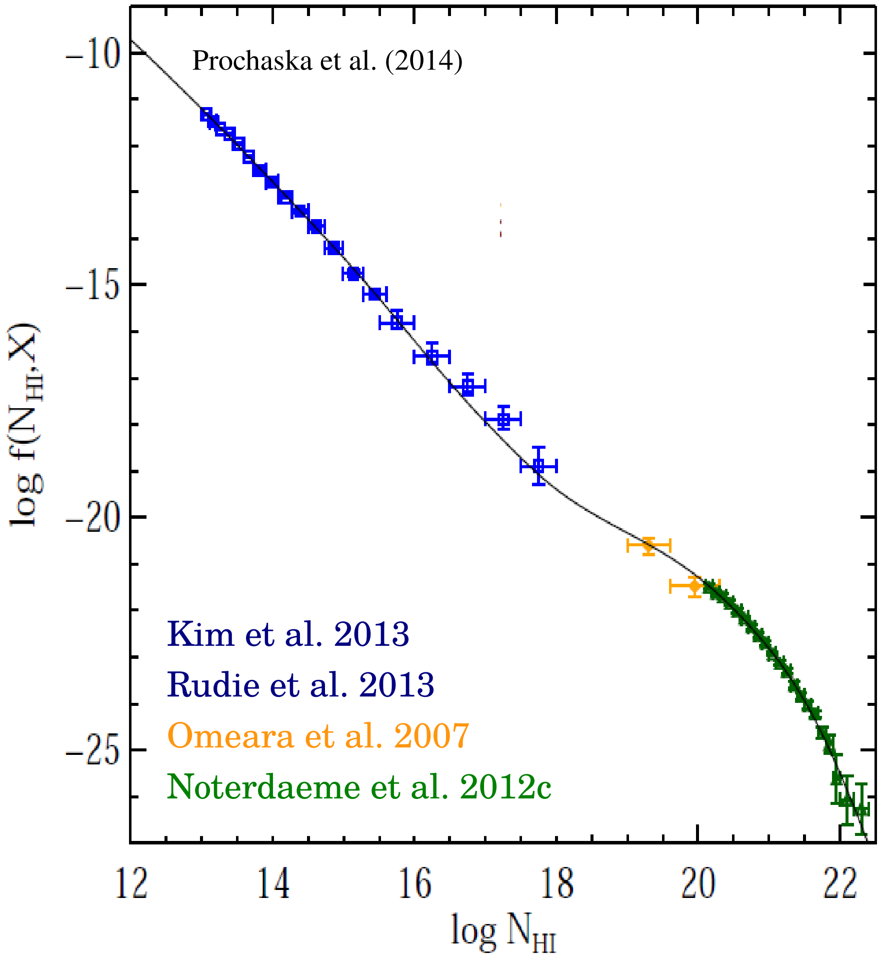
H_2 microphysics
Krumholz & McKee
Sternberg et al.

$$\sum_{HI\to H2} \approx \frac{10\, M_\odot\, pc^{-2}}{Z}$$

PROBING THE DISTANT UNIVERSE







- Random lines of sight wrt foreground gas

  → cosmological census of the gas

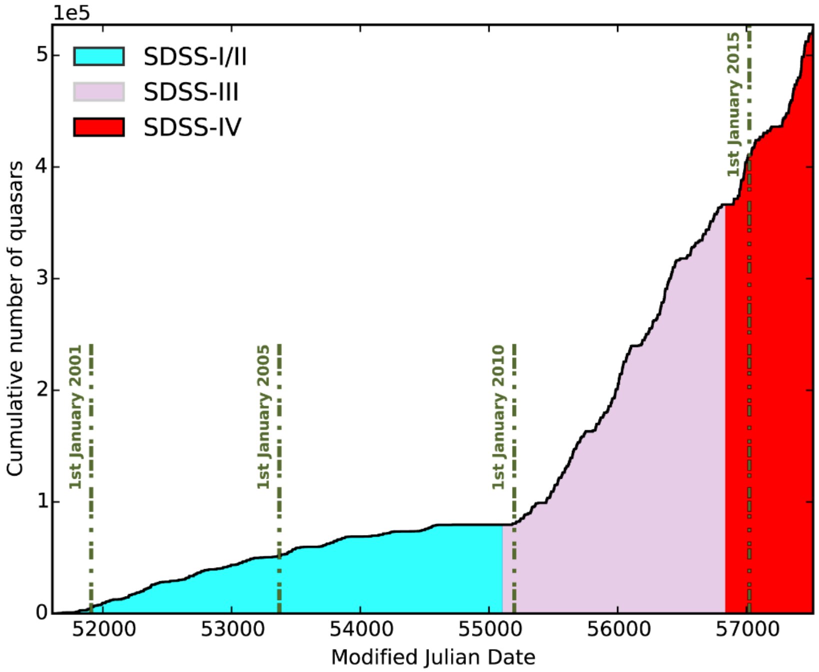
- Ly-alpha forest: mostly ionised, IGM

  → Large-scale structures, BAO

- Lyman-limit systems: CGM

- Damped Lyman-alpha systems: Neutral gas. Inside galaxies (ISM) ??

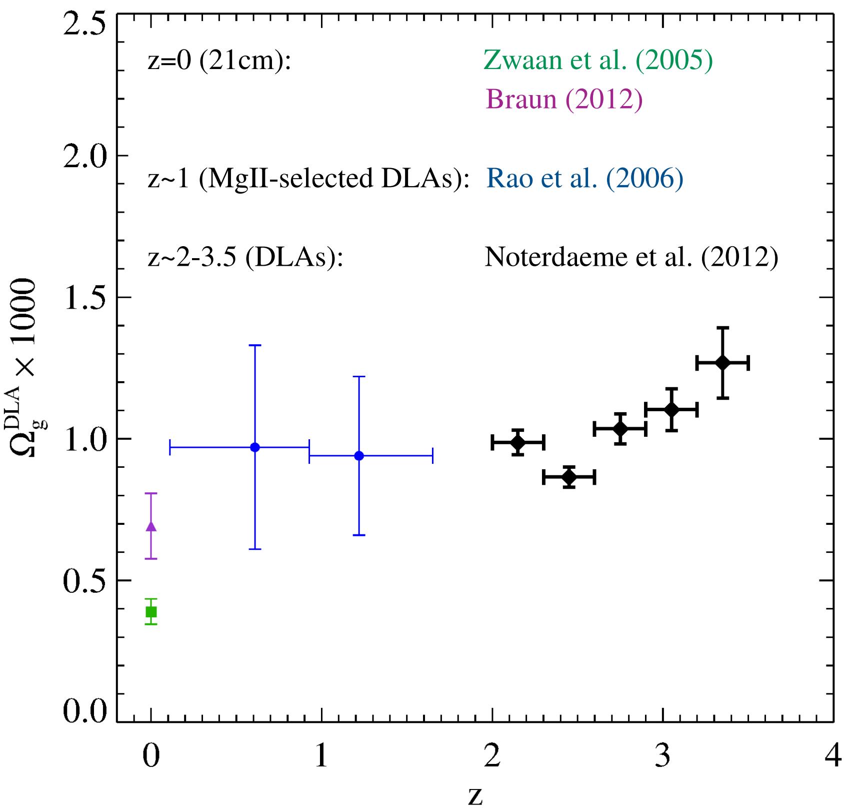
INTERVENING DAMPED LYMAN-ALPHA SYSTEMS



> half a million quasar spectra
R = 2000 ; λ = 360-1000 nm

> 30 000 DLAs at z~2-4

Although DLAs contain the bulk (~80%) of the neutral atomic gas in the Universe, this not enough to account for baryons in stars today.



INTERVENING DAMPED LYMAN-ALPHA SYSTEMS

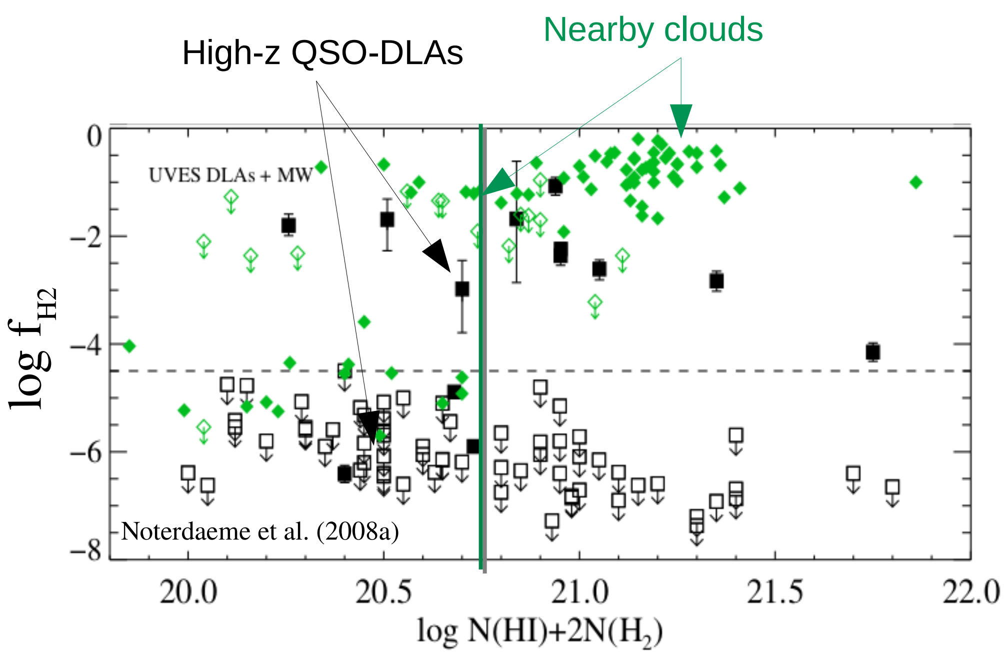
$N(HI) \geq 2\times10^{20}$ cm^{-2}

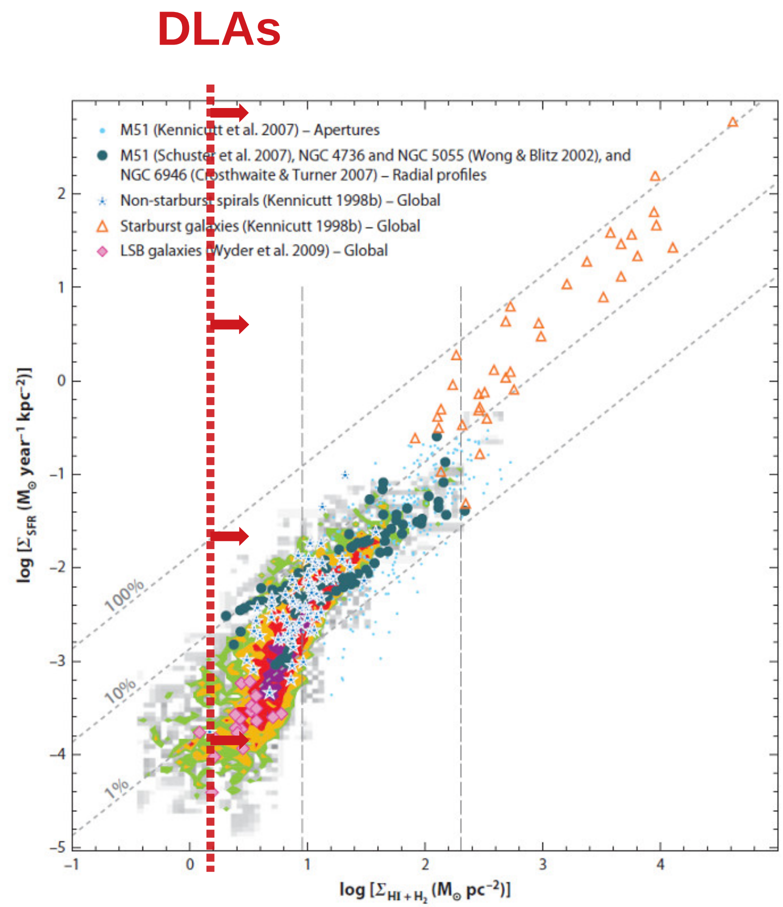
→ Neutral gas

→ Surface density ~ what is seen in nearby galactic disks and similar to observed towards nearby stars.

- Star-formation ?

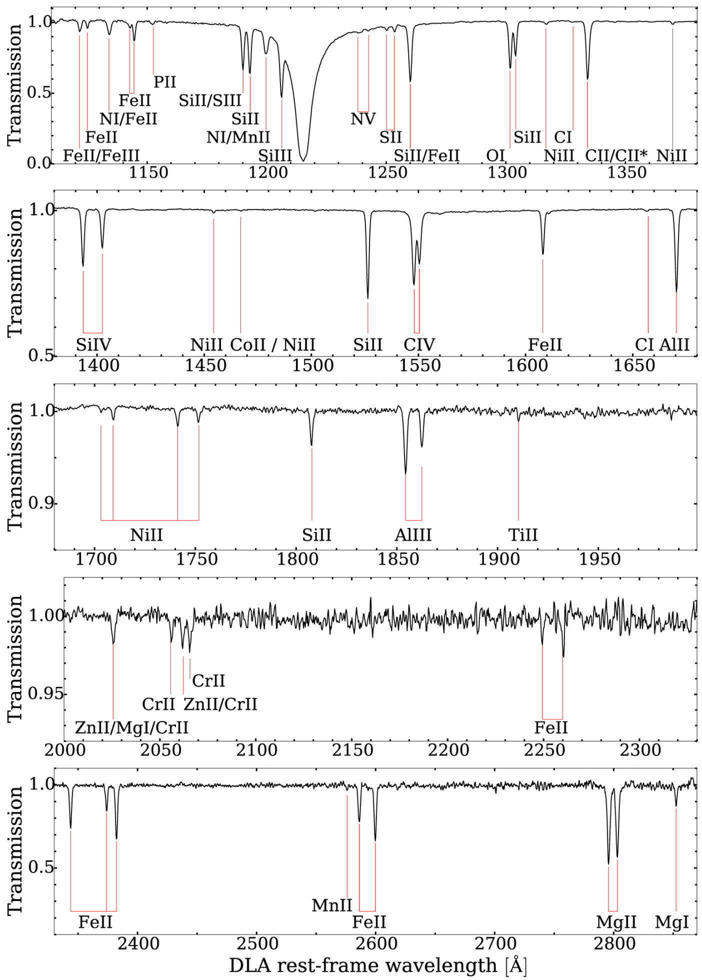
- Molecular gas ?



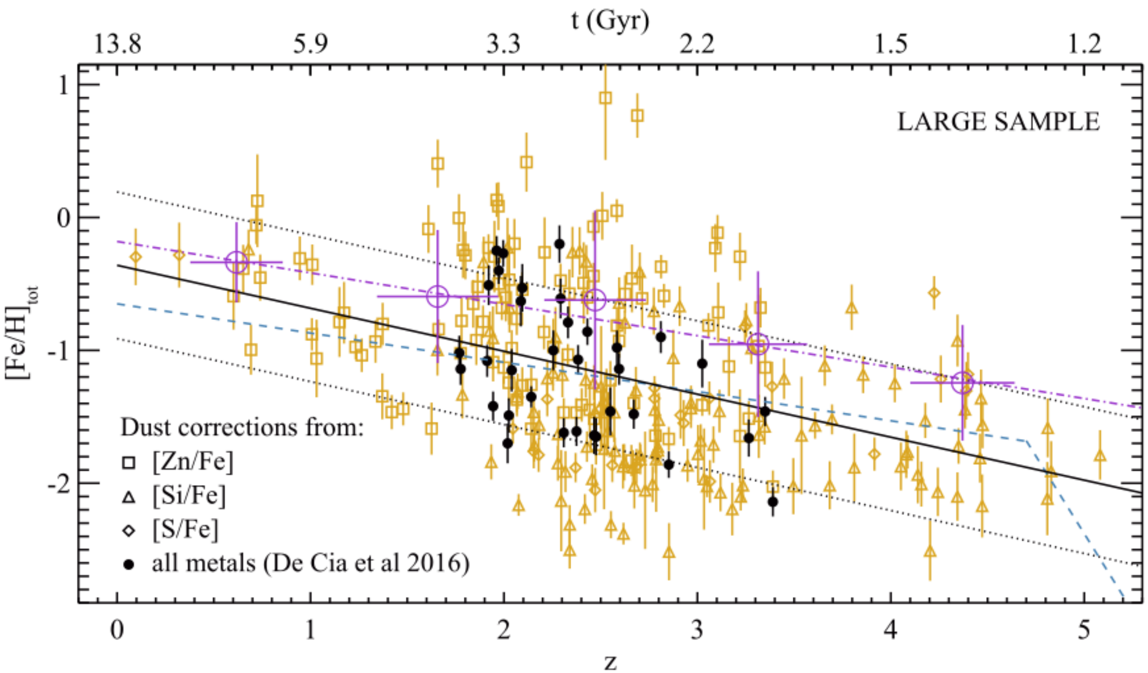


INTERVENING DAMPED LYMAN-ALPHA SYSTEMS

Metallicity evolution



Absorption-line measurements are direct, robust and precise.

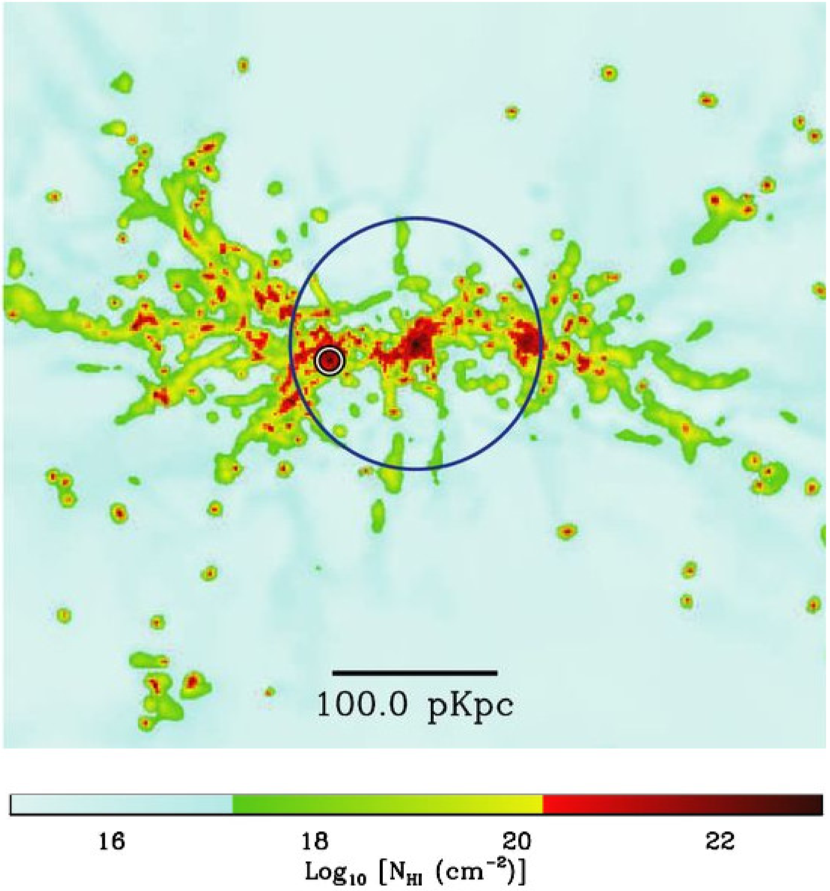


Most DLAs have low metallicities

INTERVENING DAMPED LYMAN-ALPHA SYSTEMS

Intervening absorbers are located far from the background source and intercepted according to the gas cross-section

Intervening DLAs:
- probe the neutral gas
- typically have low metallicities
- typically have low molecular fractions
- Associated galaxies are faint and/or far



GRB ABSORBERS

- GRB afterglows are bright, and detectable at high redshift

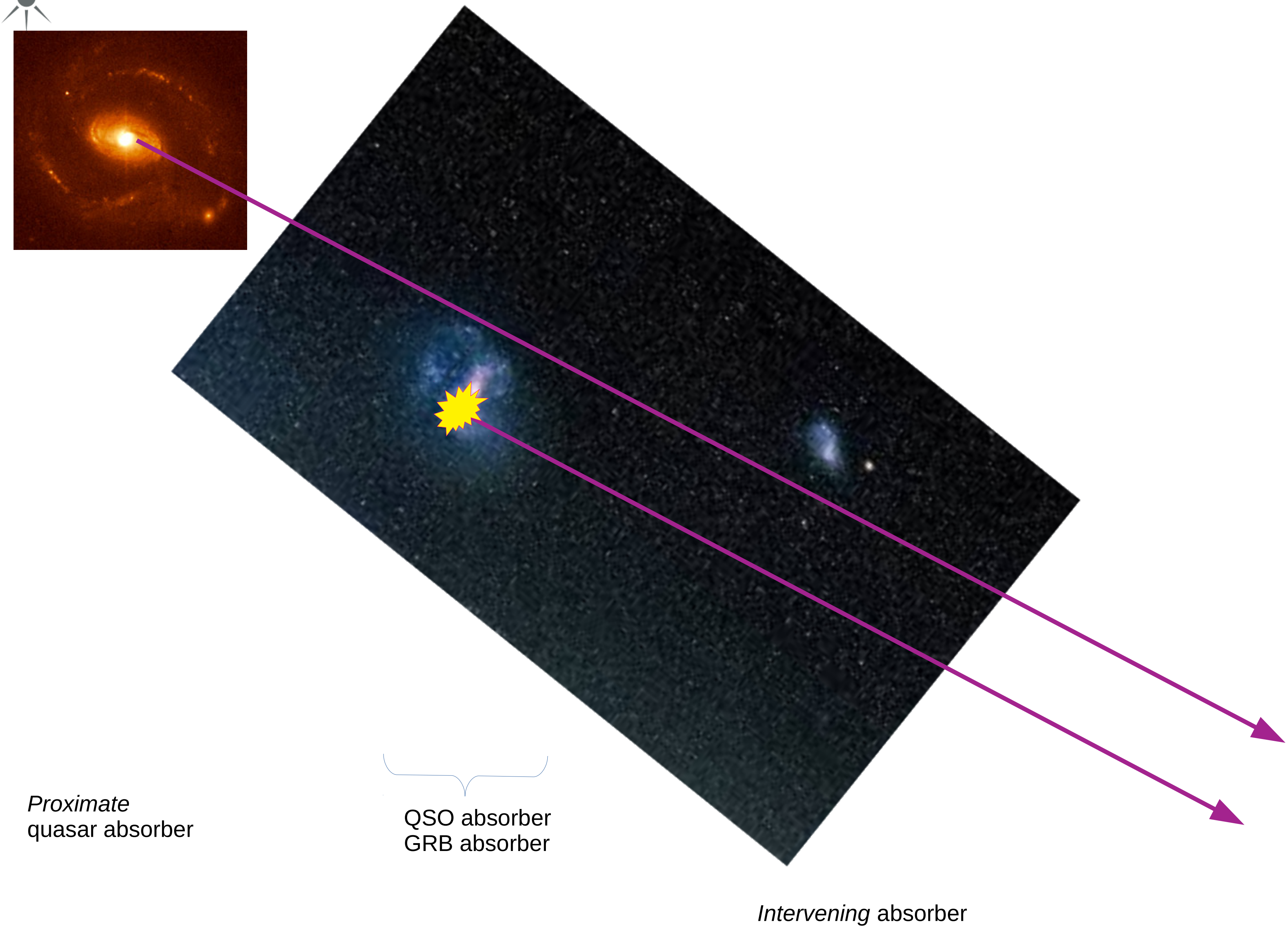
  → Probe of intervening gas ?

- GRBs are linked to the death of a massive star

  → Signalize regions of distant star-formation : Great potential to use $N_{GRB}(z)$ as tracer of $\Omega_{SFR}(z)$. BUT: dependence on metallicity ? Need to know much as possible about their immediate environment.

  → Probe of ISM in the host galaxies

QSO vs GRB ABSORBERS : Jargon



Intervening GRB absorbers

- In principle, we expect no differences in the properties and statistics of intervening absorbers if observed towards GRB or quasar.

Dealing with small statistics and heterogeneous samples : **the MgII crisis**

- Prochter et al. (2006) found **4** times more strong intervening MgII towards GRBs than towards quasars : dust extinction bias for QSO? Gravitational lensing ? Contamination from high-velocity systems local to the GRB? Difference in beam size ?

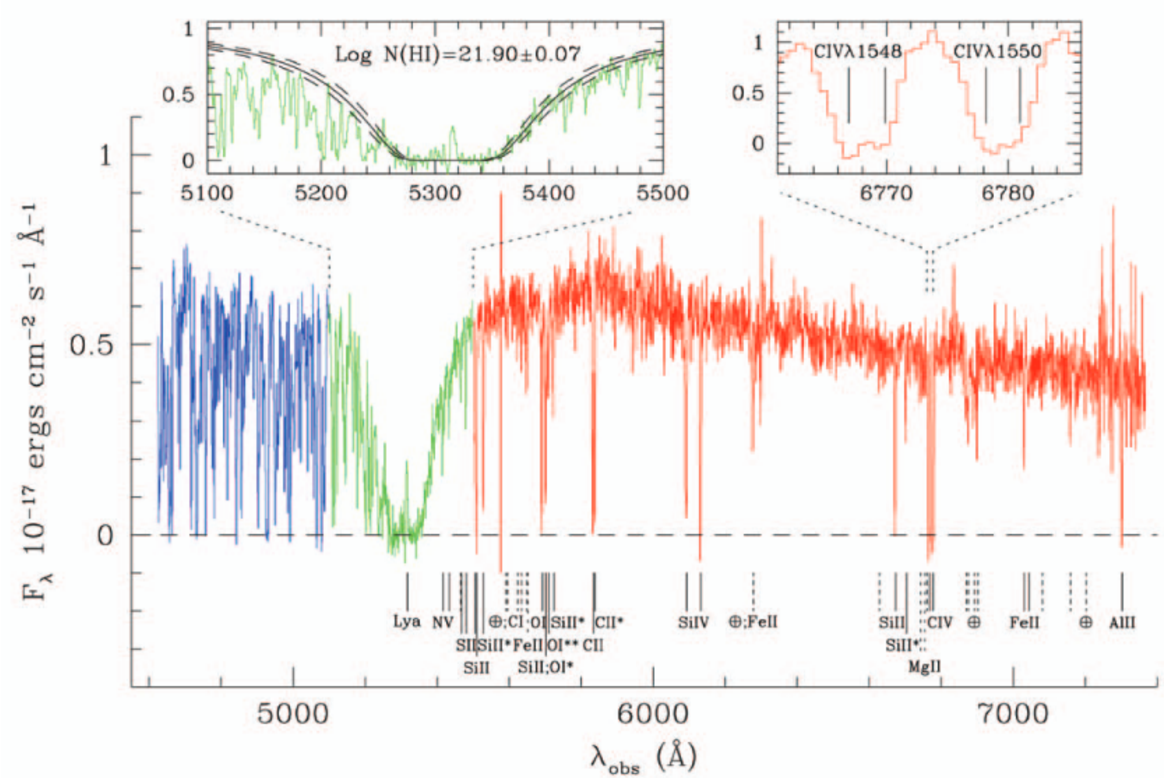
- Vergani et al. (2009), excess of factor **2** only.

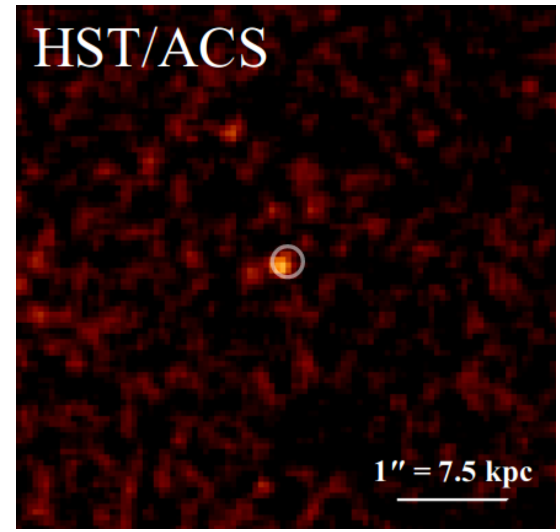
- Christensen et al. (2017): no excess.

→ As quasar, GRBs can be used to probe intervening systems but statistics remain much smaller. Main potential at very high-z.

$z_{DLA} = z_{GRB}$

Vreeswijk et al. (2004)



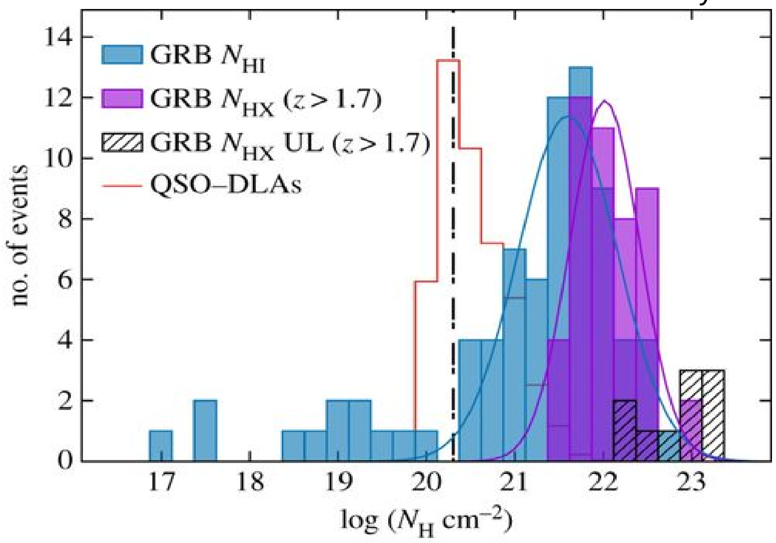


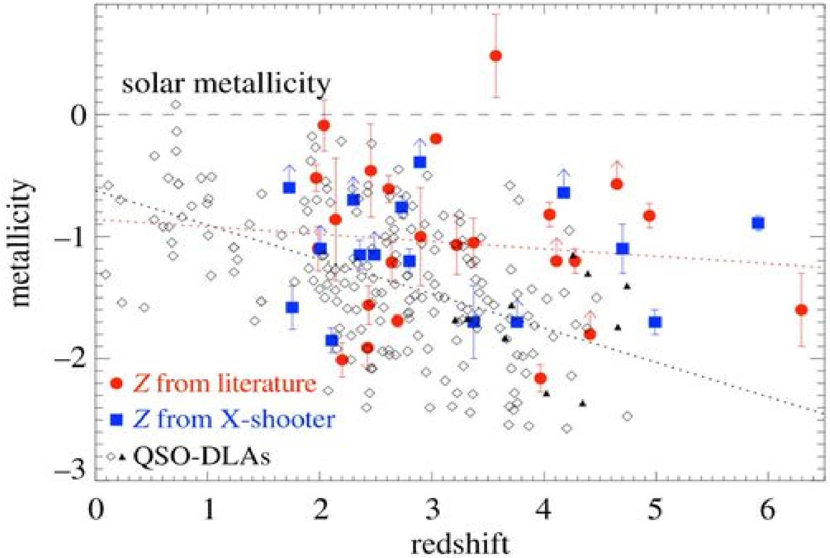
Wainwright et al. (2005)

SFR ~ 1 $M_\odot\,yr^{-1}$

GRB-DLAs: N(HI) and metallicities

From Schady+17





- $N(H)_X > N(H)_{Lya}$: ionised gas, HeI, or excess absorption by IGM ?
  → IGM too metal poor?
  → Correlation between $N(H)_X$ and M* supports absorption in GRB host

<u>N(HI) about 10 times higher in GRB-DLAs than in QSO-DLAs, with slightly higher metallicities</u>

GRB-DLAs: Paucity of H_2 ?

Location within galaxy

Large N(HI)
Higher metallicities than QSO-DLAs

H_2 was expected to be common in GRB-DLAs, but...

MISSING MOLECULAR HYDROGEN AND THE PHYSICAL CONDITIONS OF GRB HOST GALAXIES

Jason Tumlinson,[1] Jason X. Prochaska,[2] Hsiao-Wen Chen,[3]
Miroslava Dessauges-Zavadsky,[4] and Joshua S. Bloom[5]

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ABSTRACT

We examine the abundance of molecular hydrogen (H_2) in the spectra of gamma ray burst afterglows (GRBs). In nearby galaxies, H_2 traces the cold neutral medium (CNM) and dense molecular star-forming interstellar gas. Although H_2 is detected in at least half of all sight lines toward hot stars in the Magellanic Clouds and in ≈25% of damped Lyα systems toward quasars, it is not detected in any of the five GRB environments with a similar range of neutral hydrogen column density and metallicity. We detect no vibrationally excited H_2 that would imply that the GRB itself has photodissociated its parent molecular cloud, so such models are ruled out unless the parent cloud was $\lesssim$4 pc in radius and was fully dissociated prior to the spectroscopic observations, or the star escaped its parent cloud during its main-sequence lifetime. The low molecular fractions for the GRBs are mysterious in light of their large column densities of neutral H and expectations based on local analogs, i.e., 30 Doradus in the LMC. This surprising lack of H_2 in GRB damped Lyα absorbers indicates that the destruction processes that suppress molecule formation in the LMC and SMC are more effective in the GRB hosts, most probably due to a combination of low metallicity and an FUV radiation field 10–100 times the Galactic mean field. These inferred conditions place strong constraints on the star-forming regions in these early galaxies.

Assuming CNM:
(see Krumholz+)

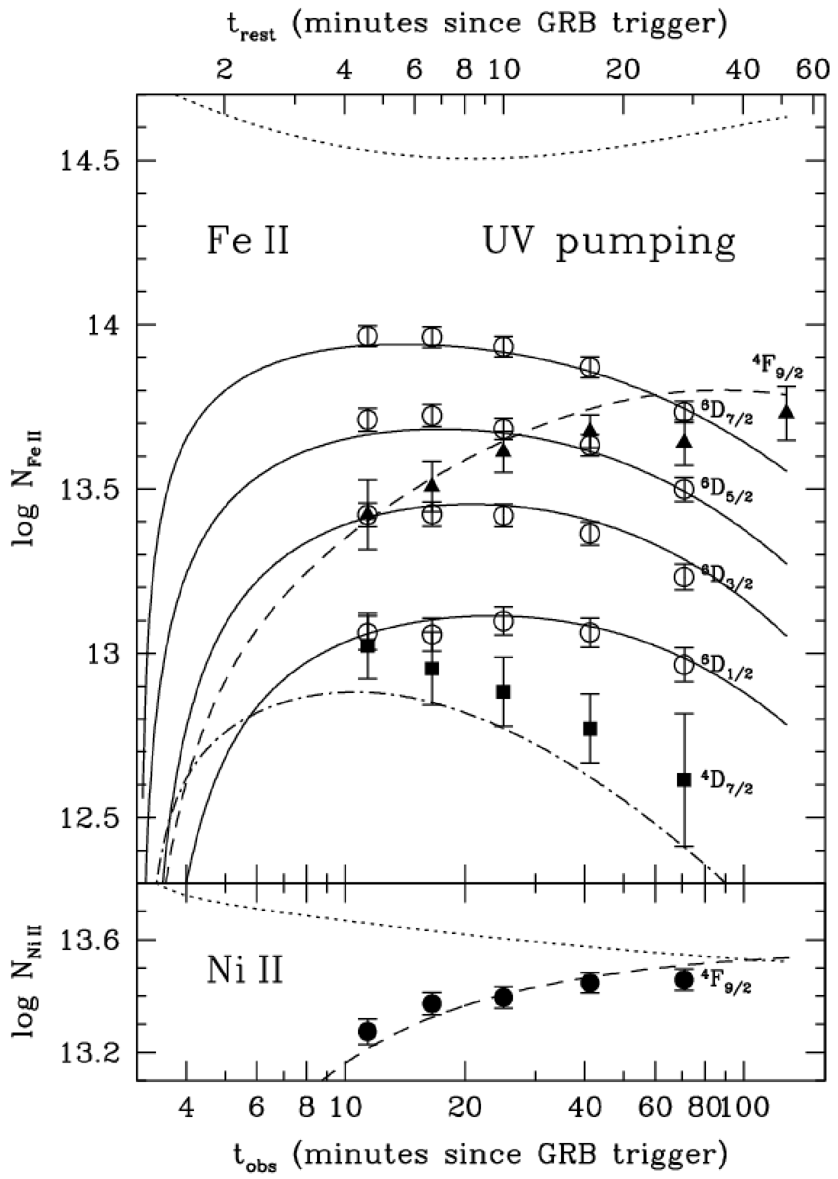
$$\sum_{HI \rightarrow H2} \approx \frac{10\, M_{\odot}\, pc^{-2}}{Z}$$

More generally:
(Bialy, Sternberg+)

$$\Sigma_{\rm H\,I} = \frac{6.71}{\tilde{\sigma}_{\rm g}} \ln\left(\frac{\alpha \rm G}{3.2} + 1\right) {\rm M_{\odot} pc^{-2}}$$

$$\alpha G = 0.59\, I_{UV} \left(\frac{100\,{\rm cm^{-3}}}{n_{\rm H}}\right)\left(\frac{9.9}{1 + 8.9\tilde{\sigma}_g}\right)^{0.37}$$

GRB-DLAs : distance to explosion site



Vreeswijk et al. (2007) :

d > 1.7 kpc

GRB-DLAs probe the host, not the immediate environment of the GRB.

GRB-DLAs : No lack of H_2

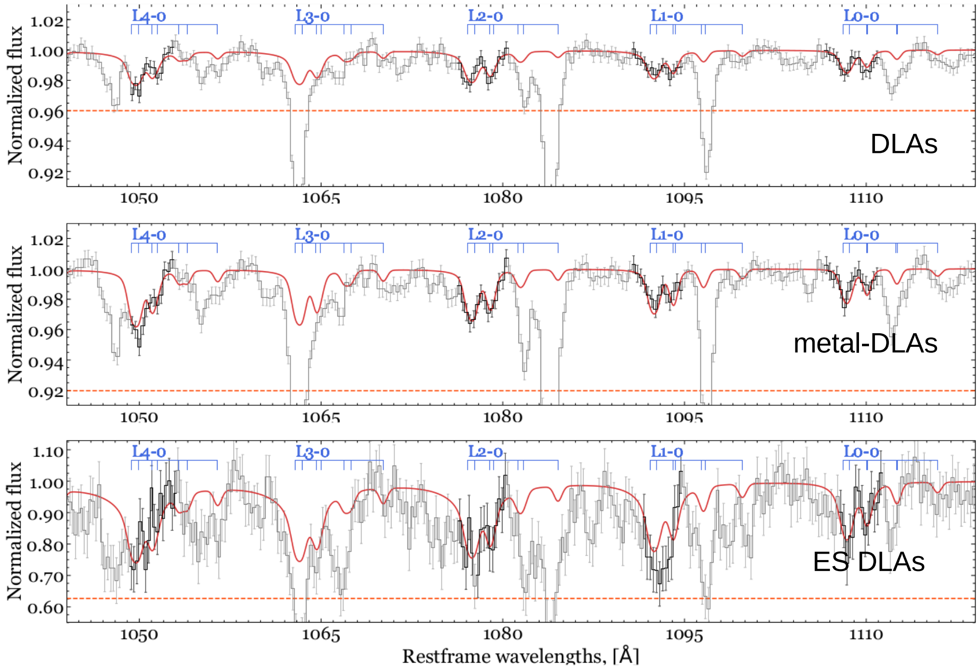
Bolmer et al. (2019):

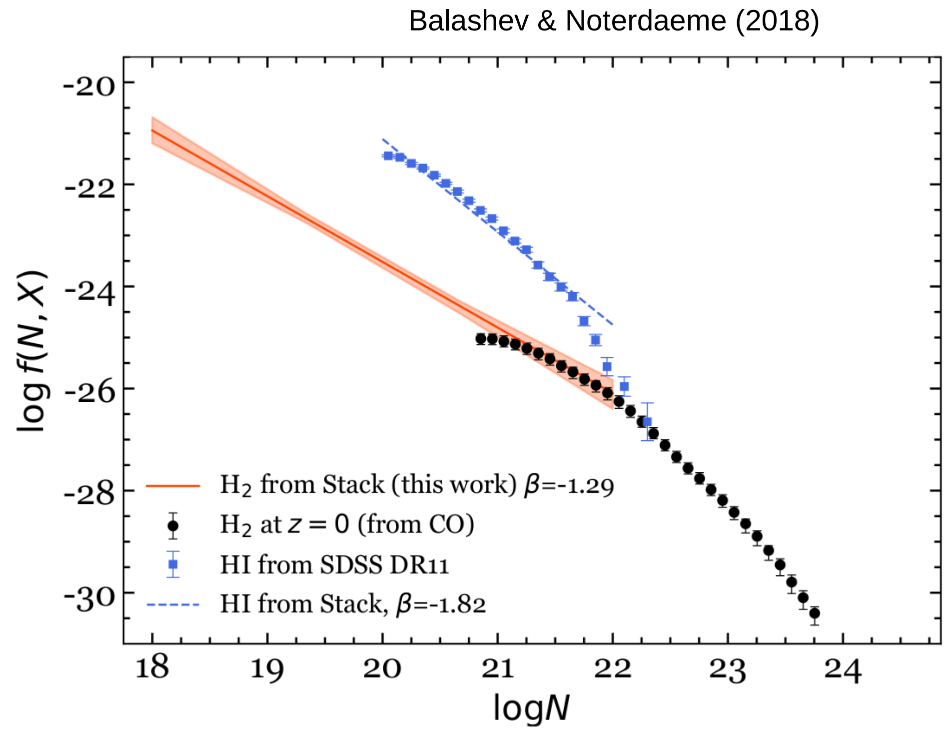
- 22 GRB afterglows observed with VLT/Xshooter

- 6 firm H_2 systems + tentative 3 → 30-40% H_2 incidence rate

There is no lack of H_2 in GRB-DLAs compared to QSO-DLAs...it could now even be the other way round.

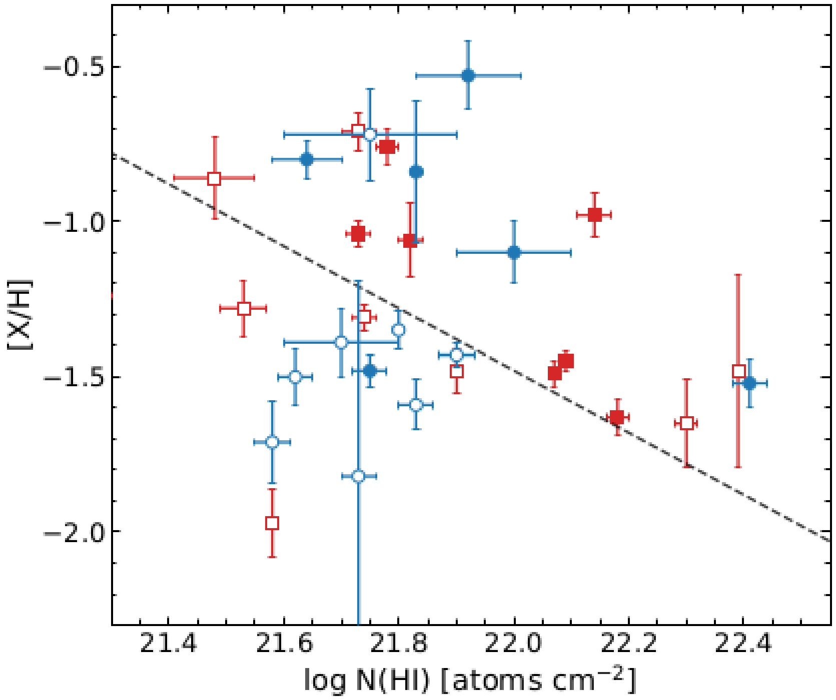
Comparing apples with apples : The very high N(HI) end





→ Significant increase of H_2 incidence at very large N(HI) (ESDLAs) : ~30%

Comparing apples with apples : The very high N(HI) end



GRB-DLAs
QSO-ESDLAs

Similar H_2 incidence when looking at similar N(HI) and Z

Need to investigate the physical conditions in details to assess the possibility of higher UV field in the case of GRB-DLAs.

H_2 balance + H_2 excitation → Rotational and vibrational levels

+ Abundances and excitation of other species.

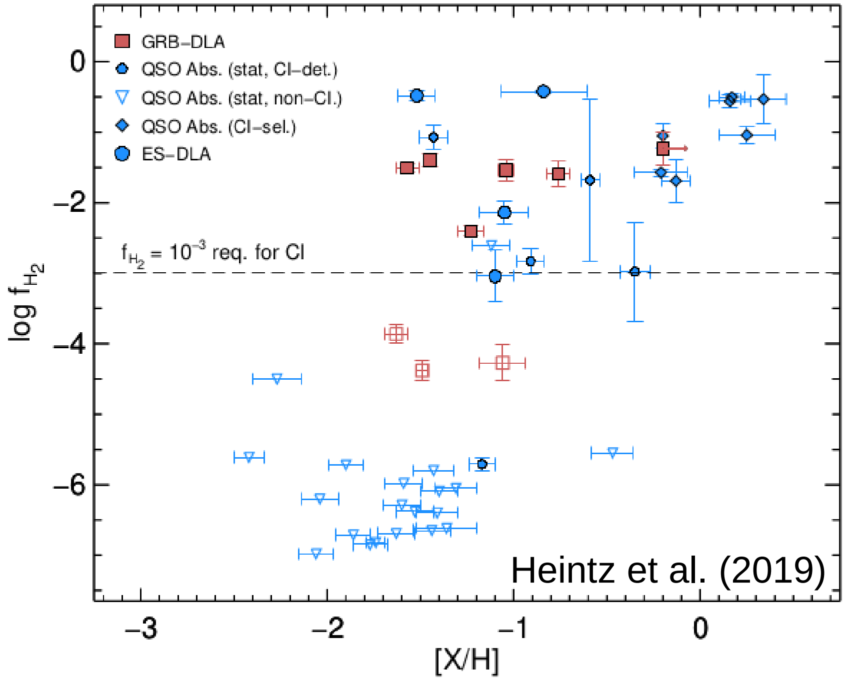
Search for the hosts in emission !

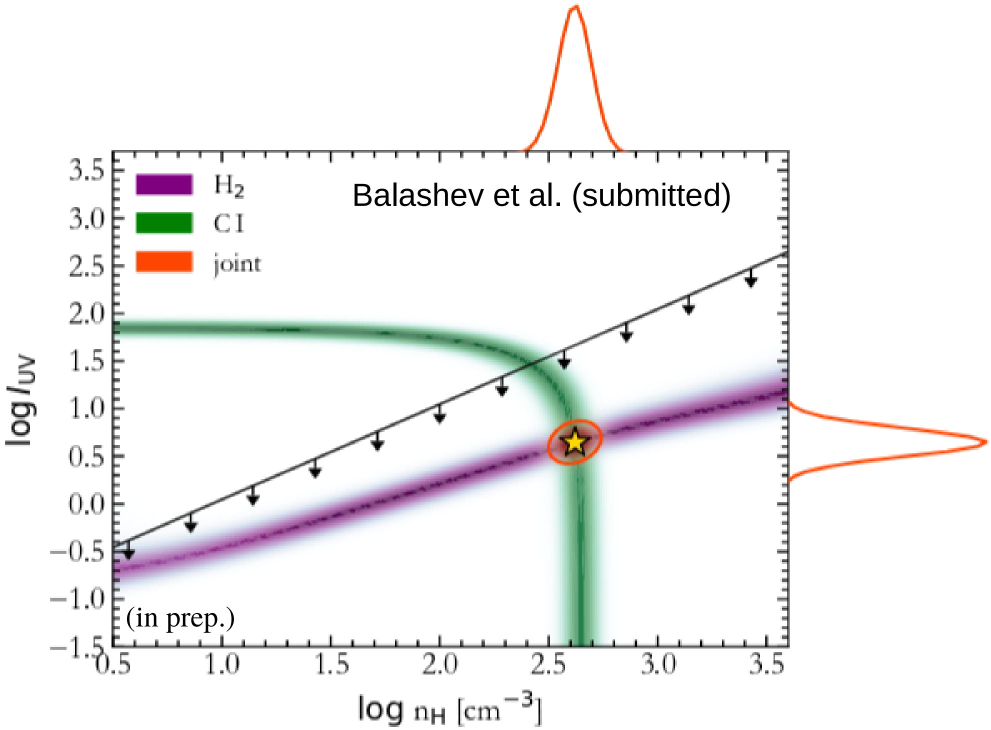
Neutral carbon

→ Neutral carbon traces high metallicity molecular gas (Noterdaeme et al. 2018)

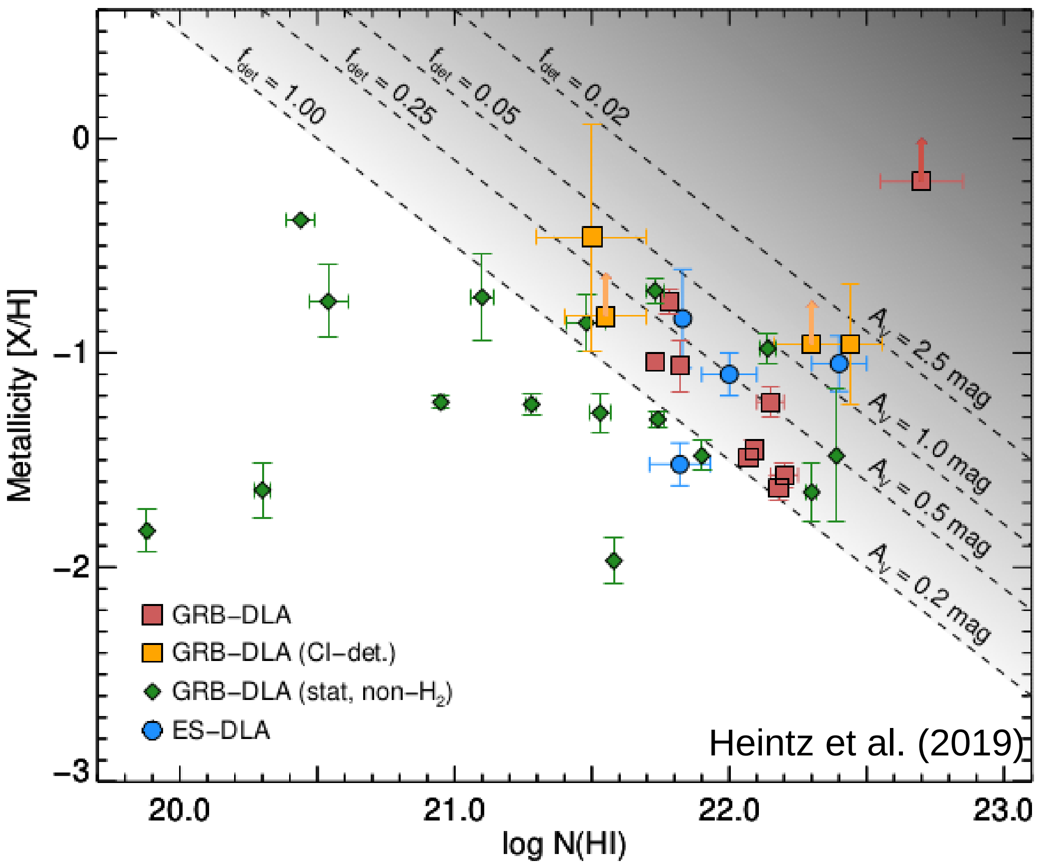
→ Similar chemical conditions required for CI in GRB-DLAs and QSO-DLAs (Heintz et al. 2019)

→ Fine-structure levels very useful to derive physical conditions

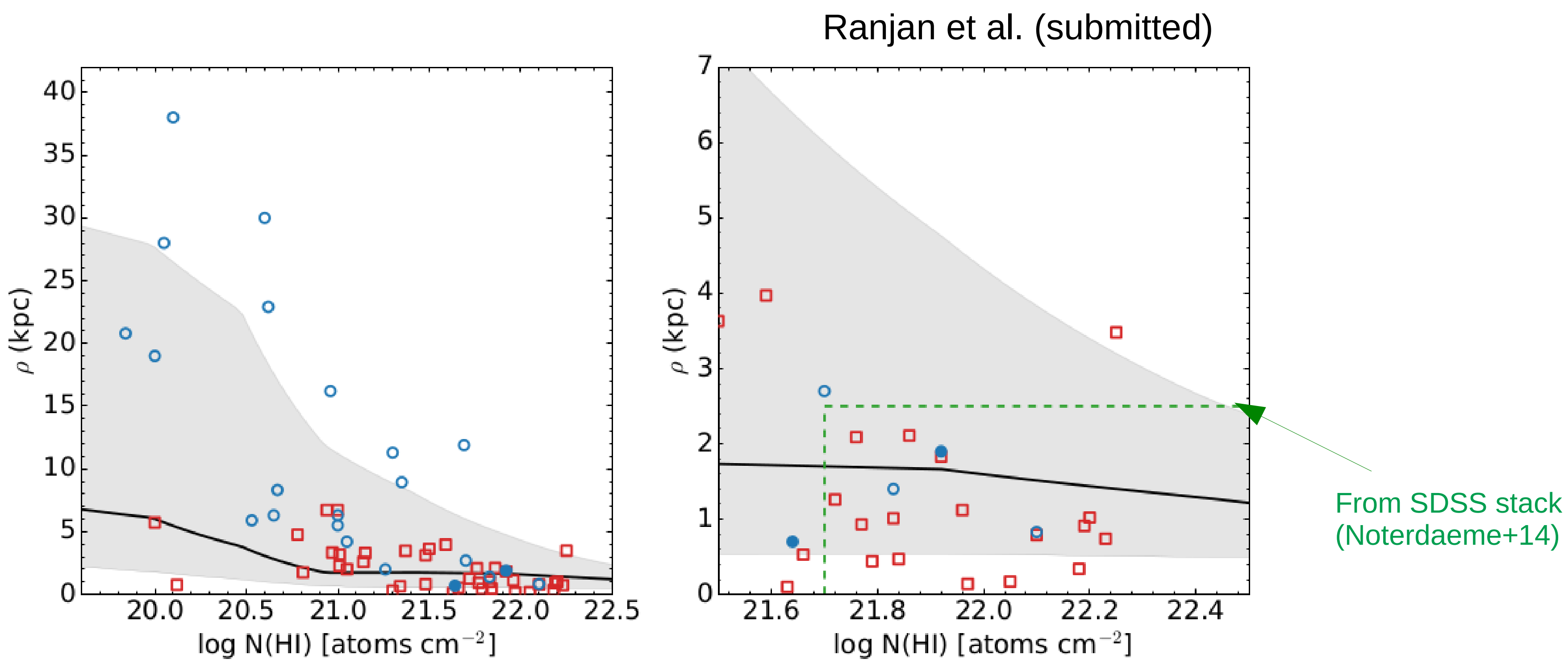




The dust bias



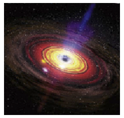
DLA hosts

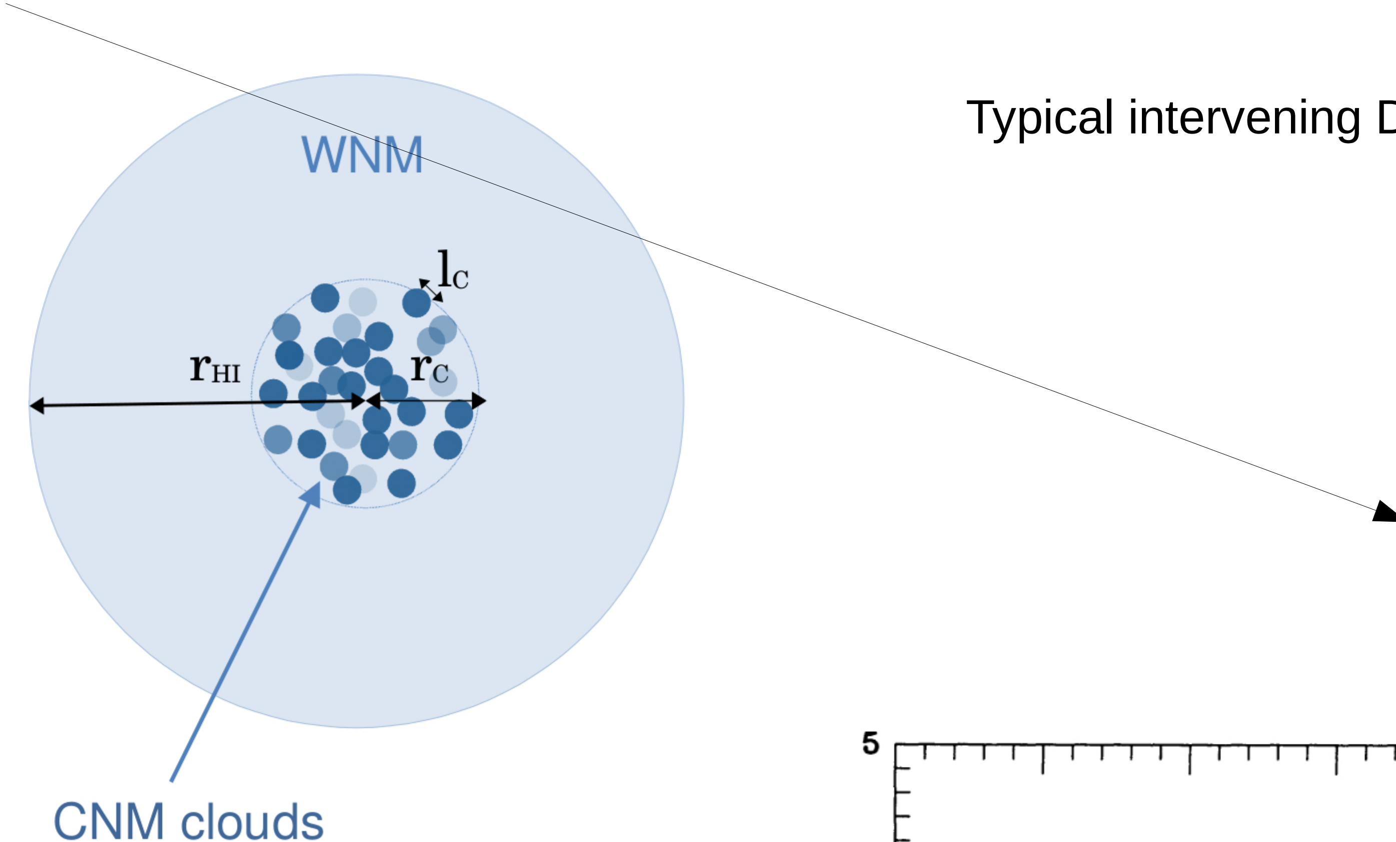


We confirm that extremely strong intervening DLAs occur at small galacto-centric distances (a few kpc)

The non-detection of associated galaxy for several QSO-DLAs is more likely due to very low SFRs than being located outside the aperture.

Simple model



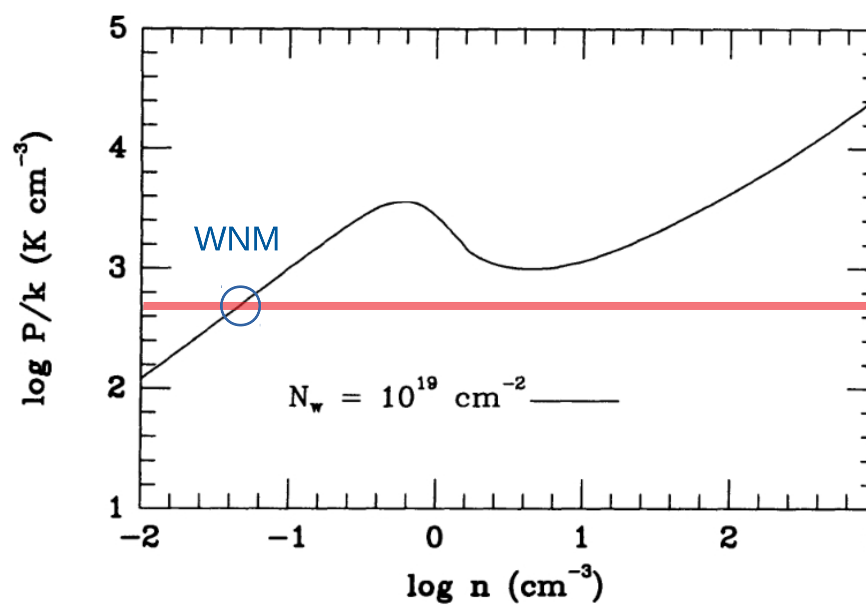


Typical intervening DLA

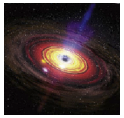
l_C~0.1pc

r_C > 1kpc

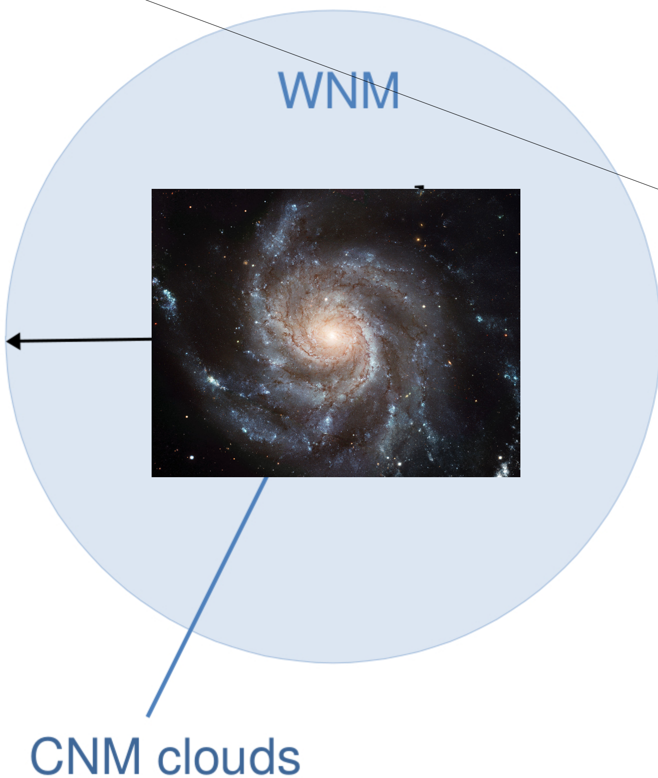
r_{HI} ~10-30 kpc



Simple model



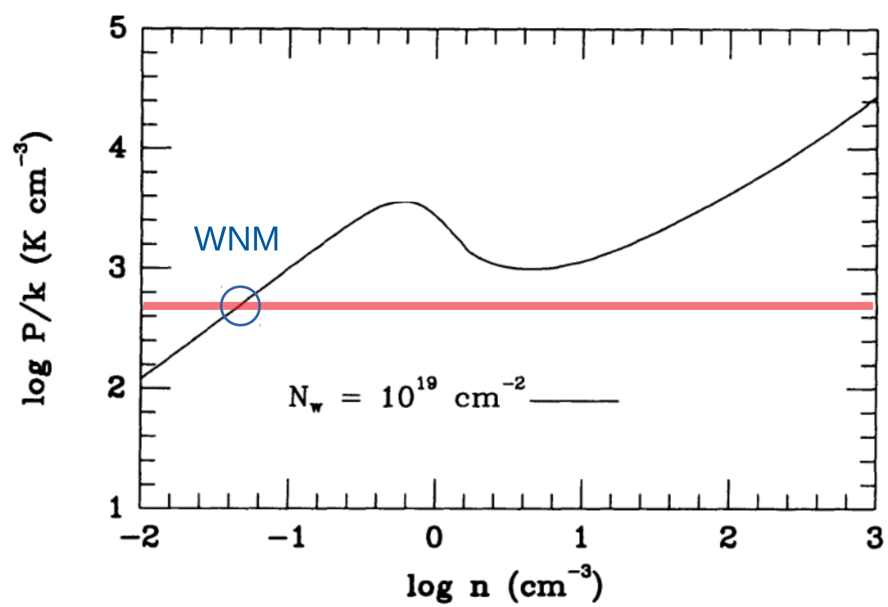
Typical intervening DLA



$l_C \sim 0.1$pc

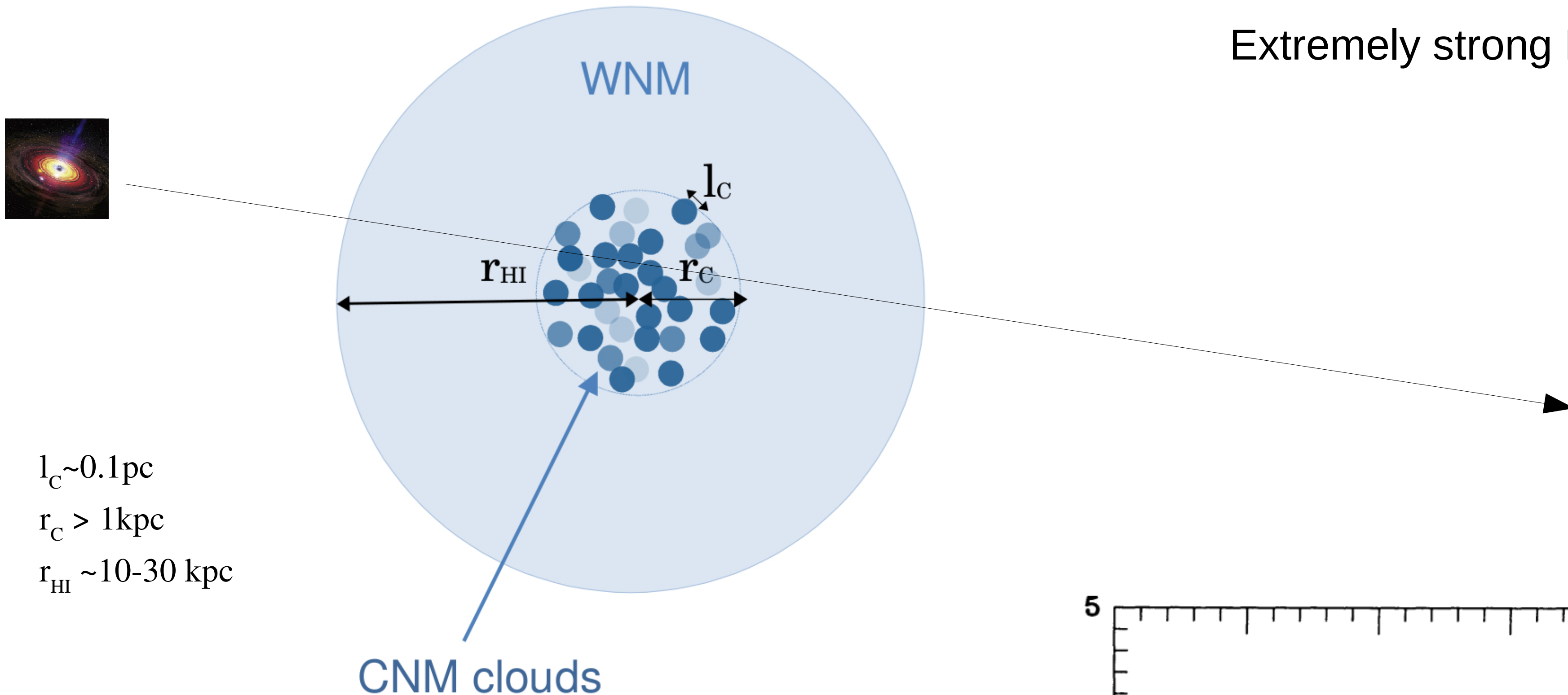
$r_C > 1$kpc

$r_{HI} \sim 10$-30 kpc



Simple model

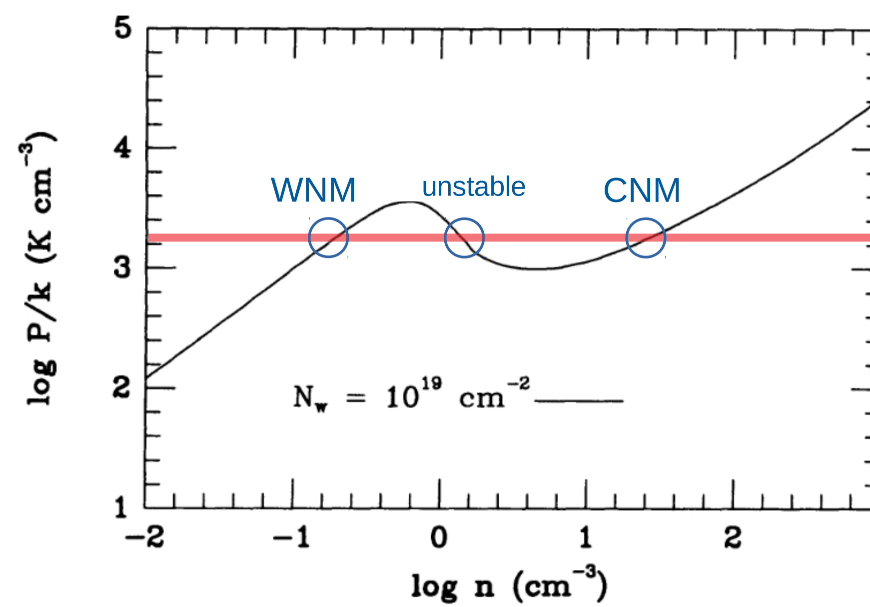
Extremely strong DLA



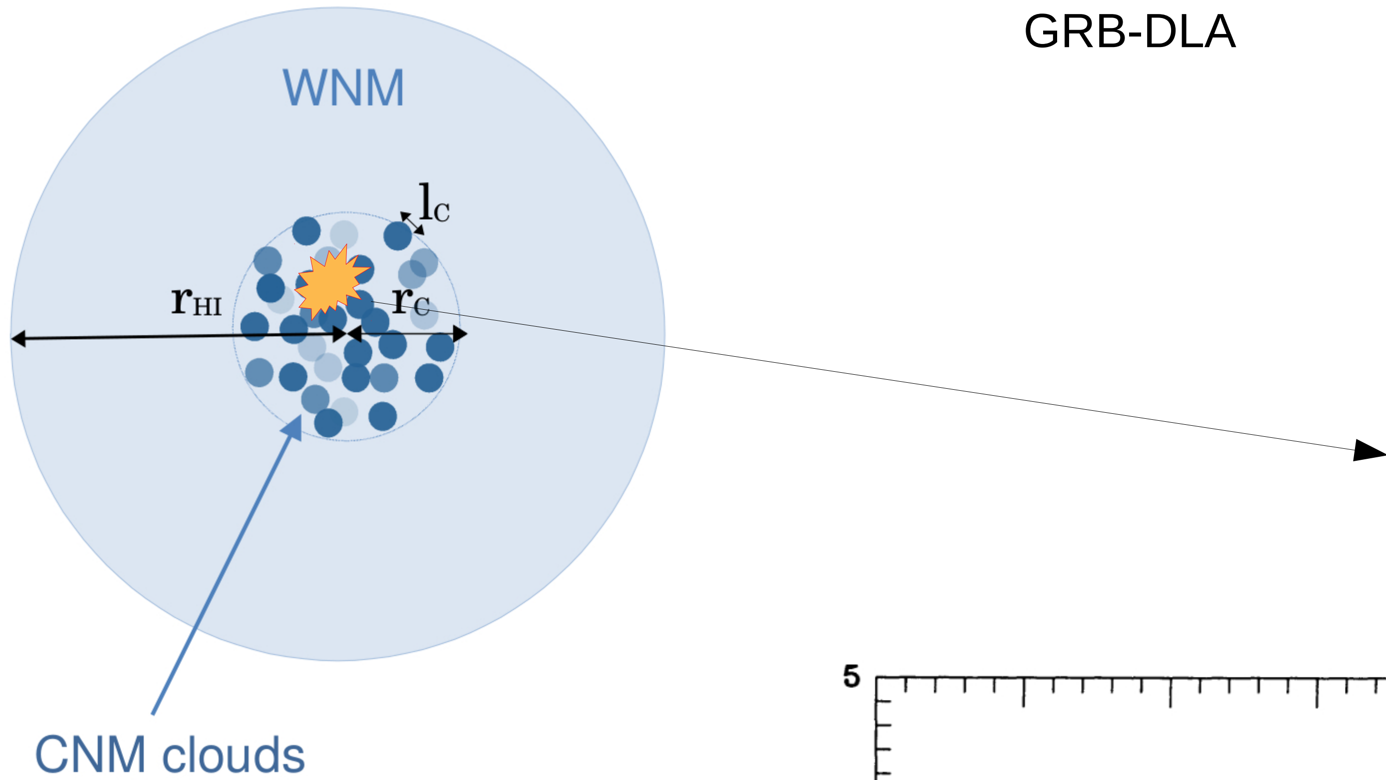
l_C~0.1pc

r_C > 1kpc

r_{HI} ~10-30 kpc



Simple model



l_C~0.1pc

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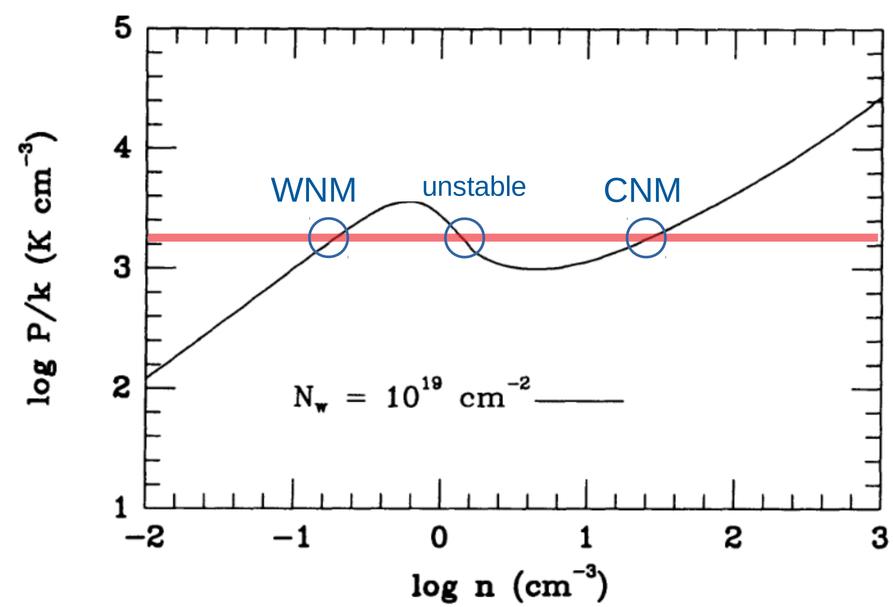
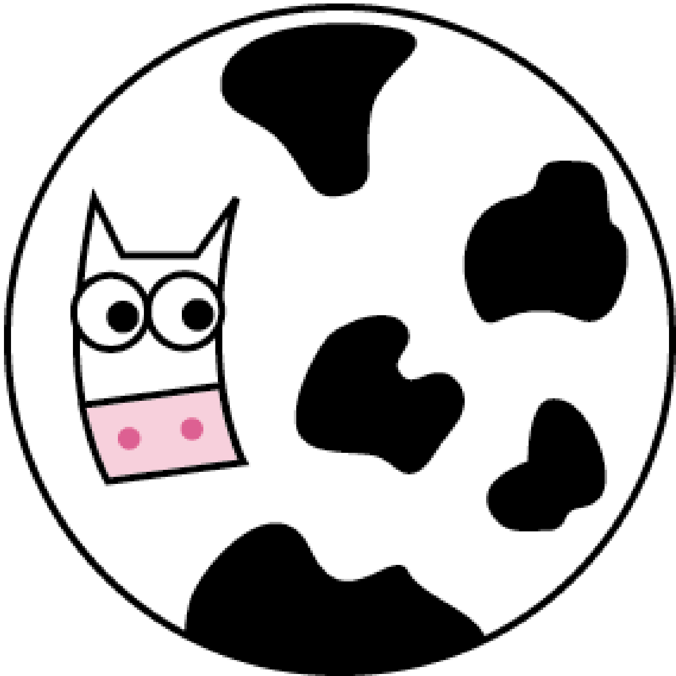


Simple model



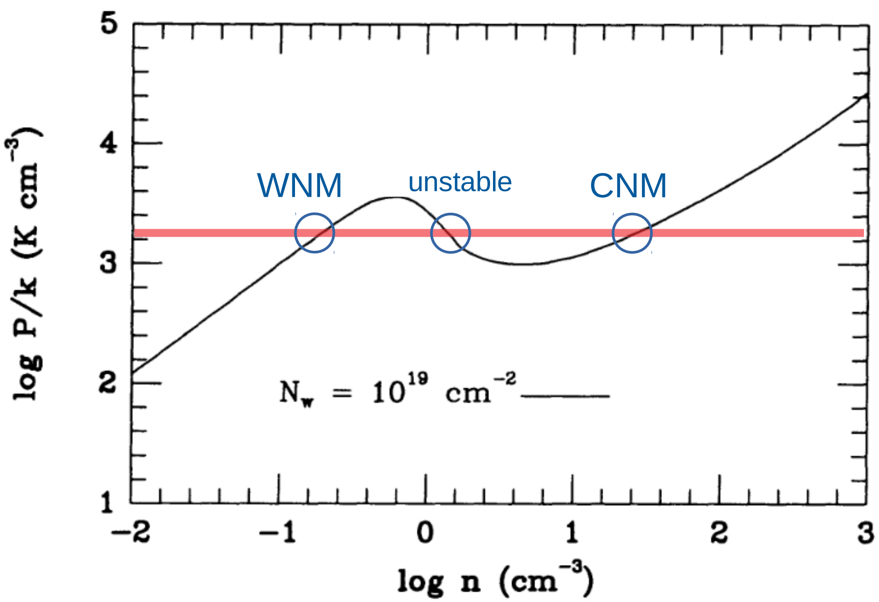
CNM clouds

GRB-DLA

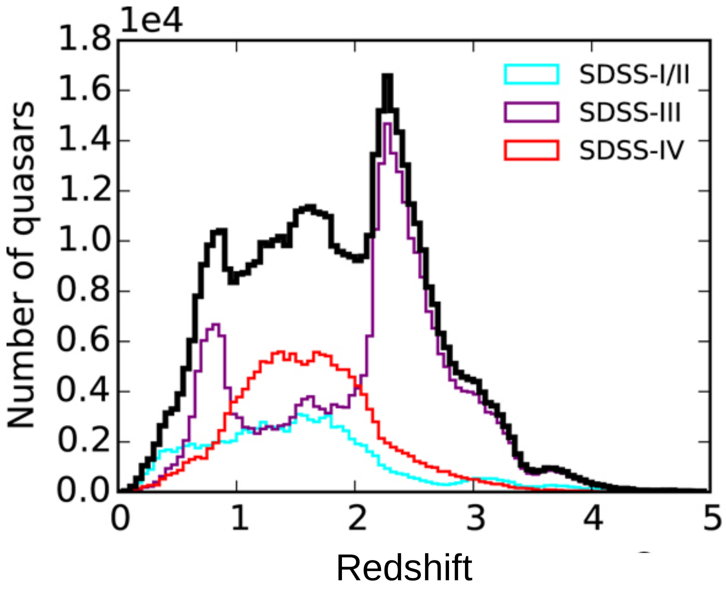
l_C~0.1pc

r_C > 1kpc

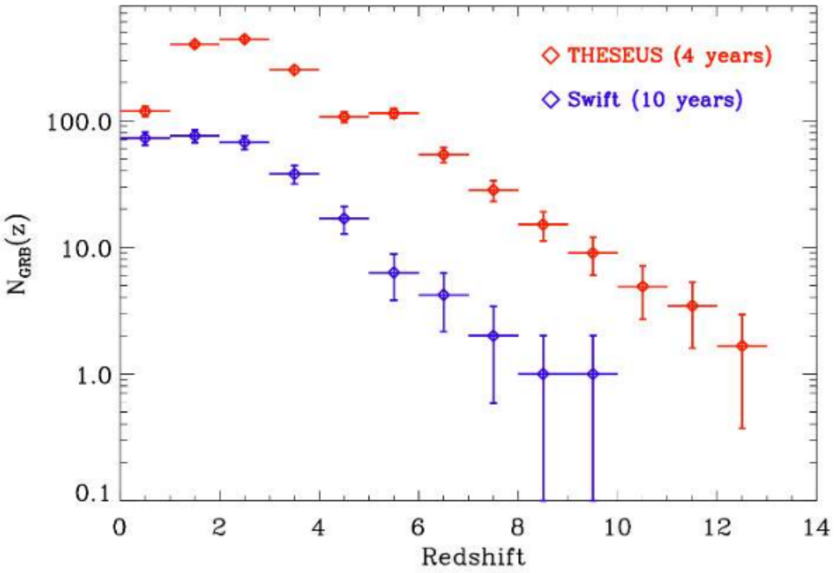
r_{HI} ~10-30 kpc



QSOs vs GRBs



Vergani, THESEUS Workshop 2017



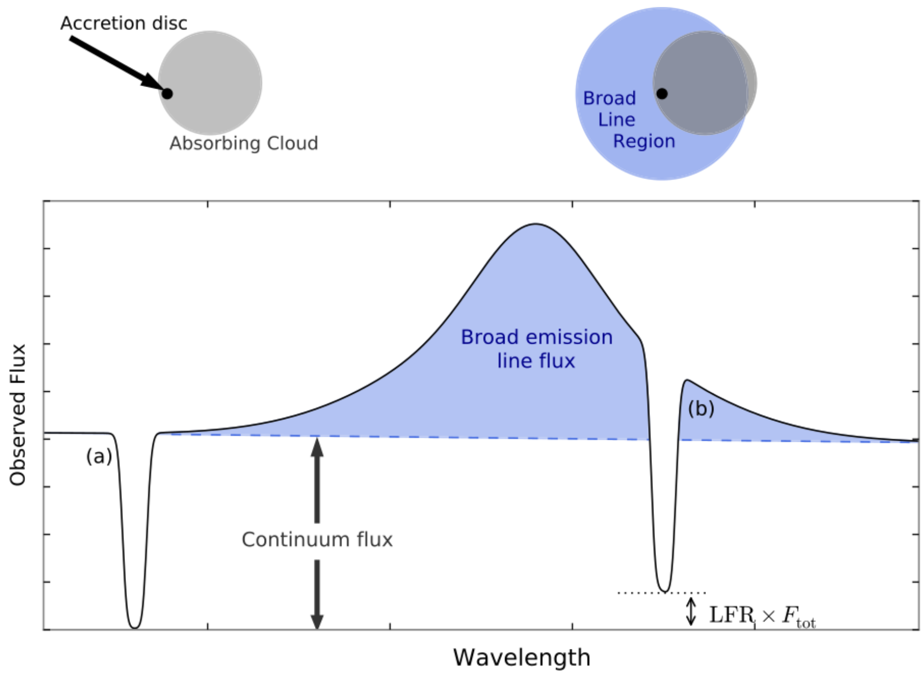
→ Intervening absorbers: QSOs remain far more numerous...but GRBs have potential at very high-z.

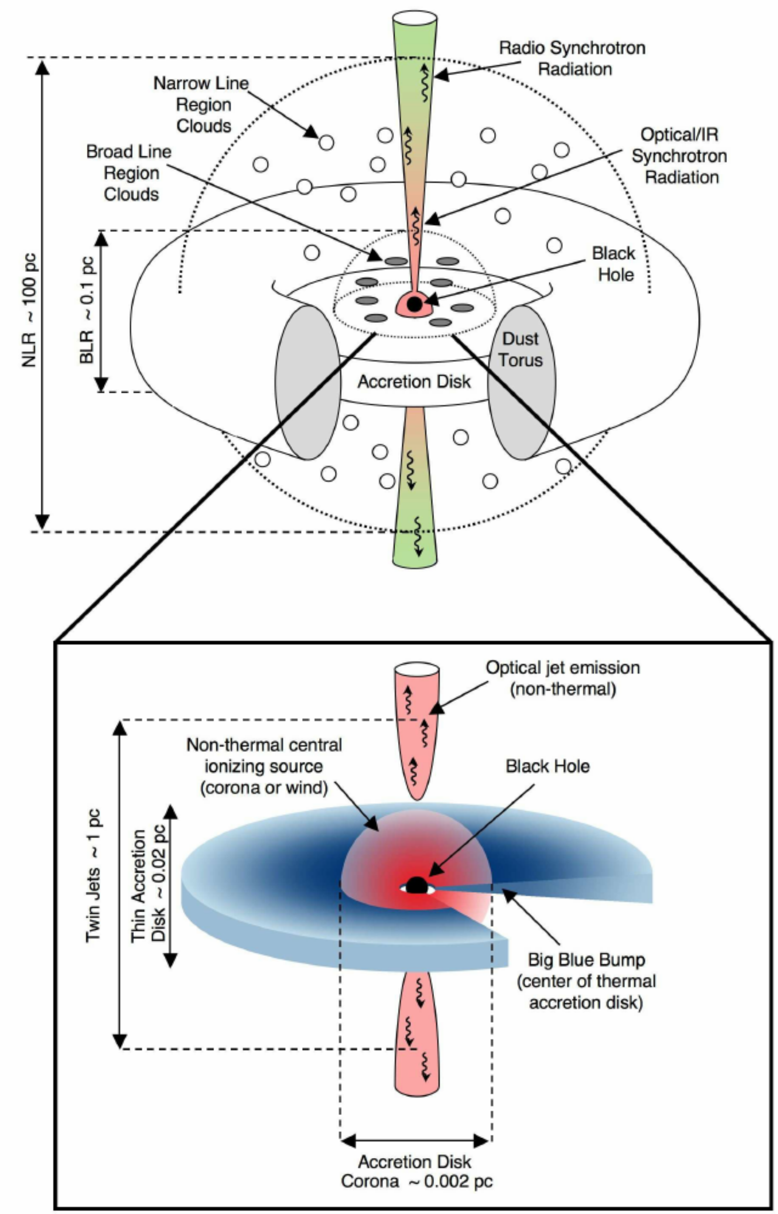
→ **Small galacto-centric radii** (a few quasars l.o.s., ~all GRBs)

→ SFRs : zero prior in case of intervening systems

→ Structures in the light beam ?

QSOs vs GRBs





QSOs: different scales for different portions of the spectra.

→ Partial coverage of molecular gas on top of emission lines

→ Partial coverage of neutral gas on top of Ly-alpha (proximate DLAs)

<u>GRB afterglows: extremely narrow pencil beam</u>

CONCLUSION

- IGM studies (*intervening*) at z<4 require very large statistics which can currently only be offered by quasars + LBGs (soon) **BUT** GRBs have strong potential to probe higher redshifts.

- GRB-absorbers and QSO-absorbers share similar properties (Metallicities, Depletion, Extinction (?), Kinematics) when restricting to a same high column density regime.

- Dust bias affects both type of sources. However, GRB afterglows can be very bright and hence unique probes of gas with high extinction (e.g. molecular cloud by Prochaska et al. 2007).

- Small pencil beam for GRB afterglows, more complex structure for quasars (generally ignored up to recently, but starts to be interesting).

- When taking account for selection effects, do GRB absorbers probe the same population of galaxies as quasar absorbers ? Is the UV field really 10-100 times Galactic ? Are LGRB only originating in low-metallicity environments?

→ detailed studies of the physical/chemical conditions are still required
→ need to increase statistics (93 GRB afterglows in X-shooter legacy sample)
→ Understanding ISM microphysics will be eased by comparing properties in a variety of environment (e.g. H_2 in quasars).